Appendix E – Soils

The following Appendix contains eight separate soils documents: soil transect methods, soil hazard ratings, concise soil descriptions, soil types and burn severity by unit, expected soil conditions after proposed activities, subsoiling suitability, sediment export from logging units during Summit Fire salvage, and effects of feller-buncher operation on soil bulk density.

Soil Transect Methods

Categorize the soil conditions using the *Soil Class Disturbance Definitions* and the *Soil Assessment Data Forms*. When calculating the percentage of an activity area that contains detrimental soil conditions, use the percentage of points designated as Class 2 and Class 3. Do not sample non-forest inclusions. The following method was used:

Transects: Find a “no impact” area to calibrate your foot/sharpshooter. Also, find an obvious skid trail or landing to get a feel for detrimental compaction. Use a minimum of 1 transect across a representative section of the unit (this is not a statistical sample). From the beginning of the transect walk in a straight line sampling every 4-5 feet (1 pace). The line can be bent, to ensure the area crossed is representative. Collect a minimum of 200 points along each transect. Record soil impacts at each sampling point based on *Soil Class Disturbance Definition.*

Description of Detrimental Soil Conditions[1]

Detrimental Compaction – An increase in soil bulk density of 20 percent, or more, over the undisturbed level for volcanic ash soils. For all other soils it is an increase in soil bulk density of 15 percent, or more, over the undisturbed level. Assess changes in compaction by sampling bulk density, macro porosity, or penetration resistance in the zone in which change in relatively long term and that is the principal root development zone. This zone is commonly between 4 to 12 inches in depth.

Detrimental Displacement – The removal of more than 50 percent of the topsoil or humus enriched A horizon from an area of 100 square feet, or more, which is at least 5 feet in width.

Detrimental Puddling – When the depth of ruts or imprints is 6 inches or more. Soil deformation and loss of structure are observable and usually bulk density is increased.

Detrimental Surface Erosion – Visual evidence of soil loss in areas greater than 100 square feet, rills or gullies and/or water quality degradation from sediment or nutrient enrichment.

Detrimental Burned Soil – Top layer of mineral soil has been significantly changed in color, oxidized to a reddish color, and the next one-half inch blackened from organic matter charring by heat conducted through the top layer. The detrimentally burned soil standard applies to an area greater than 100 square feet, which is at least 5 feet in width.

[1]FSM 2500 – Watershed and Air Management R-6 Supplement 2500-98-1

Soil Disturbance Class Definitions

Class 0: Undisturbed Natural State.

Soil surface:
- No evidence of past equipment operation.
- No depressions or wheel tracks evident.
- Litter and duff layers present and intact.
- No soil displacement evident.

Class 1: Low Soil Disturbance

Soil surface:
- Faint wheel tracks or slight depressions evident (e.g. <2" deep).
- Litter and duff layers usually present and intact.
- Surface soil has not been displaced.
- Some evidence of burning impacts including a mosaic of charred and intact duff layer to partially consumed duff layer with blackened surface soil.

Soil resistance to penetration with tile spade or probe:
- Resistance of surface soils may be slightly greater than observed under natural conditions. Concentrated in top 0-4 inch depth.

Observations of soil physical conditions:
- Change in soil structure from crumb or granular structure to massive or platy structure, restricted to the surface 0-4 inches.

Class 2: Moderate Disturbance

Soil surface:
- Wheel tracks or depressions evident (e.g. 2-6" deep.
- Surface soil partially intact with minimal displacement (area must meet the size requirement).

Soil resistance to penetration with tile spade or probe:
- Increased resistance is present throughout top 4-12 inches of soil.

Observations of soil physical conditions:
- Change in soil structure from crumb or granular structure to massive or platy structure, restricted to the surface 4-12 inches.
- Platy structure is generally continuous and holds together when shaken.
- Large roots may penetrate the platy structure, but fine and medium roots may not.

Class 3: High Disturbance

Soil surface:
- Wheel tracks or depressions highly evident (e.g. >6" deep)
- Evidence of topsoil removal, gouging and piling.
- Soil displacement has removed the *majority* of the surface soil. Subsoil partially or totally exposed.
- Burning consumed duff layer, root crowns and surface roots of grasses. Evidence of severely burned soils (mineral surface soil red in color) in an area that meets the size requirement.

Soil resistance to penetration with tile spade or probe:
- Increased resistance is deep into the soil profile (>12 inches).

Observations of soil physical conditions:
- Change in soil structure from granular structure to massive or platy structure extends beyond the top 12 inches of soil.
- Platy structure is continuous.
- Roots do not penetrate the platy structure.

Unit:_____________________________ Date:___________________
Who:________________________
(form date:10-19-02)
Approximate years since latest skidding: % in roads & landings?
(previous sale & unit?)

Where are transects? (describe or sketch map)

0 | 1
| 2 | 3

Number of previous entries: How much machine piling? Skid trail spacing:

Any off-skid-trail disturbance visible? Can & should existing skid trails be reused? If not, why not?

What are "2" & "3" due to: displacement, compaction? How much displacement?

Note conditions that may call for special mitigations: steep slopes, scab inclusions, ephemeral "streams", draws, moist soil (put on map if possible)

General range of soil characteristics:
Slope % shovel penetration depth coarse fragment abundance & size
texture how much ash?

Suitability of the soil for subsoiling in terms of depth, stoniness, and slope:

Is one part of unit hit harder than others?

Do these transects appear representative of other parts of unit?

General notes

Soil Hazard Ratings

Mapping Unit	Surface Erosion Hazard	Compaction Hazard	Displacement Hazard	Puddling Hazard	Natural Stability
3	L-M	M-H	L	L-H	VS
31	L-M	M	M	L	VS
32	M	M	H	L	VS
33	M-H	M	M	L	VS
34	VH	L-M	M	L	VS
35	VH	L-M	L	L	VS
36	M	M	H	L	VS
37	M-H	L-M	L	L	VS
41	L-M	M-H	L-M	L	VS
42	M	M	H	L	VS
46	M-H	L-M	L-M	L	VS
47	H	L	L-M	L	VS
58	L	M	H	L	VS
59	M	M	H	L	S

Concise soil descriptions

3

Slope: 0-15%. Vegetation: Moist and dry meadow. Depth: >24 inches
These areas may or may not be sub-irrigated during the growing season. The surface soils are generally high in organic matter. Soil texture ranges from silt loams to loams to clay loams and some clays.

31

Slope: < 30%. Vegetation: ponderosa pine. Depth: 12-24 inches
Surface: gravelly loam; 30-45 % gravel & cobble by volume; 6-10 inches thick.
Subsoil: gravelly or cobbly loam; 35-50% gravel and cobble by volume; 6-14 inches thick.

32

Slope: 30-70%. Vegetation: ponderosa and mixed conifer. Depth: 18-30 inches
Surface: silt loam; up to 10% gravel by volume; 6-12 inches thick.
Subsoil: gravelly loam; 35-50% gravel and cobble by volume; 6-10 inches thick.

33

Slope: 30-70%. Vegetation: ponderosa pine. Depth: 12-24 inches
Surface: gravelly loam; 30-45 % gravel & cobble by volume; 6-12 inches thick.
Subsoil: gravelly loam or cobbly loam; 35-50% gravel and cobble by volume; 6-14 inches thick.

34

Slope: 10-70%. Vegetation: juniper, big sagebrush, ponderosa pine. Depth: 6-12 inches
Surface: gravelly to very gravelly loam; 35-65 % gravel & cobble by volume; 6-12 inches thick.

35

Slope: 30-70%. Vegetation: big sagebrush, rabbitbrush, grass. Depth: 4-8 inches
Surface: gravelly to very gravelly sandy loam; 45-70 % gravel & cobble by volume; 4-8 inches thick.

36

Slope: 30-70%. Vegetation: mixed conifer without ponderosa. Depth: 24-36 inches
Surface: silt loam; up to 10% gravel by volume; 12-18 inches thick.
Subsoil: gravelly loam; 35-50% gravel and cobble by volume; 12-24 inches thick.

37

Slope: 30-70%. Vegetation: big sagebrush, rabbitbrush, grass. Depth: 6-12 inches
Surface: gravelly to very gravelly sandy loam; 40-60 % gravel & cobble by volume; 6-12 inches thick.

41

Slope: < 30%. Vegetation: ponderosa pine. Depth: 12-30 inches
Surface: gravelly loam; 20-45 % gravel & cobble by volume; 6-10 inches thick.

Subsoil: gravelly or cobbly clay loam; 35-60% gravel and cobble by volume; 6-18 inches thick.

42

Slope: < 30%. Vegetation: ponderosa and mixed conifer. Depth: 12-36 inches
Surface: silt loam; 0-10% gravel by volume; 6-12 inches thick.
Subsoil: gravelly or cobbly clay loam; 30-50% gravel and cobble by volume; 6-24 inches thick.

46

Slope: <30%. Vegetation: juniper, scattered ponderosa pine. Depth: 8-15 inches
Surface: gravelly and cobbly loam; 30-60 % gravel & cobble by volume; 8-15 inches thick.

47

Slope: <30%. Vegetation: stiff & low sagebrush, grass. Depth: 4-12 inches
Surface: gravelly to very gravelly and cobbly loam; 30-70 % gravel & cobble by volume; 4-12 inches thick.

58

Slope: <30%. Vegetation: mixed conifer without ponderosa. Depth: 24-48 inches
Surface: silt loam; 15-24 inches thick.
Subsoil: gravelly or cobbly loam and clay loam; 30-50% gravel and cobble by volume; 9-24 inches thick.

59

Slope: 30-70%. Vegetation: mixed conifer without ponderosa. Depth: 18-48 inches
Surface: silt loam; <15% gravel and cobble; 12-18 inches thick.
Subsoil: gravelly or cobbly loam and clay loam; 30-50% gravel and cobble by volume; 6-36 inches thick.

Soil Types and Burn Severity By Unit

UNIT	logging system	soils	> 30% slope (% of unit)	compaction hazard	displacement hazard	erosion hazard	high + moderate severity burn (% of unit)	DEIS acres
001	T	31,32,33	18	M	M-H	L-H	0	43
002	S	31,32,33	69	M	M-H	L-H	91	29
004	T	31,32,33	23	M	M-H	L-H	98	162
005	T	31,32,33	14	M	M-H	L-H	0	13
006	T	31,32,33	27	M	M-H	L-H	90	58
007	T	31	2	M	M	L-M	2	35
008	S	31,32,33	73	M	M-H	L-H	97	166
009	H	32,33	88	M	M-H	M-H	8	22
010	H	31,33	78	M	M	L-H	93	35
012	T	31,33	24	M	M	L-H	76	18
013	H	31,33	66	M	M	L-H	14	6
014	H	31,33	70	M	M	L-H	78	56
016	H	31,33	73	M	M	L-H	100	2
017	S	31,33	18	M	M	L-H	99	8
018	S	31,32,33	65	M	M-H	L-H	100	31
019	H	31,36	80	M	M-H	L-M	58	36
020	H	31,32,33	58	M	M-H	L-H	100	7
022	S	31,32,33	78	M	M-H	L-H	91	85
024	H	32,33	90	M	M-H	M-H	78	43
025	H	31,32,33	57	M	M-H	L-H	78	26
026	T	31,32,33	14	M	M-H	L-H	79	29
028	T	31	8	M	M	L-M	90	24
030	S	32,33	82	M	M-H	M-H	77	131
032	T	31	9	M	M	L-M	75	55
034	T	31	12	M	M	L-M	100	97
036	H	31	1	M	M	L-M	95	5
038	T	31	1	M	M	L-M	100	93
040	T	31	12	M	M	L-M	100	70
044	S	31,32,33	63	M	M-H	L-H	75	63
048*	T	31,32,33	34	M	M-H	L-H	16	30
050	H	31,32,33	70	M	M-H	L-H	78	23
052	H	31,32,33	57	M	M-H	L-H	100	52
056	T	31	11	M	M	L-M	96	101
057	T	31	10	M	M	L-M	86	38

UNIT	logging system	soils	> 30% slope (% of unit)	compaction hazard	displacement hazard	erosion hazard	high + moderate severity burn (% of unit)	DEIS acres
058	T	31	3	M	M	L-M	24	30
060*	H	31,33	52	M	M	L-H	100	21
062	T	31,33	15	M	M	L-H	99	13
063	T	31,33	27	M	M	L-H	59	16
064	H	31,33	66	M	M	L-H	89	26
067*	T	31	3	M	M	L-M	17	60
068	H	31	9	M	M	L-M	51	20
069*	H	31,33	36	M	M	L-H	68	13
071*	H	31	1	M	M	L-M	100	5
073*	T	31	1	M	M	L-M	19	38
074*	T	31	1	M	M	L-M	82	46
075	T	31	1	M	M	L-M	3	174
077*	T	31	0	M	M	L-M	0	46
078	T	31	7	M	M	L-M	22	40
081	T	31	11	M	M	L-M	0	8
084*	S	31,32	45	M	M-H	L-M	88	17
085	S	31,32	68	M	M-H	L-M	91	34
086	T	31	15	M	M	L-M	68	57
087*	H	31,32,33	58	M	M-H	L-H	63	56
088*	H	31,32,33	41	M	M-H	L-H	90	254
090	T	31	4	M	M	L-M	91	97
100	T	31	7	M	M	L-M	88	119
102	S	31,32	17	M	M-H	L-M	98	60
104	T	31	9	M	M	L-M	11	73
110	T	31,32,33	34	M	M-H	L-H	24	5
114	T	31,32,33	18	M	M-H	L-H	8	32
116	T	31	7	M	M	L-M	88	174
118	T	31	11	M	M	L-M	75	104
120	T	31	6	M	M	L-M	16	99
122*	H	41,59	43	M-H	L-H	L-M	20	169
123	T	58,31	5	M	M-H	L-M	1	41
124	T	31,42	1	M	M-H	L-M	2	47
125	T	31,58,59	20	M	M-H	L-M	0	18
126	S	31,32	71	M	M-H	L-M	99	9
128	T	31	9	M	M	L-M	97	28

UNIT	logging system	soils	> 30% slope (% of unit)	compaction hazard	displacement hazard	erosion hazard	high + moderate severity burn (% of unit)	DEIS acres
130	T	31	9	M	M	L-M	75	103
132	H	31,32,42	82	M	M-H	L-M	4	8
134	T	42	4	M	H	M	90	38
136	S	31,32,42	72	M	M-H	L-M	35	40
138	T	42,58	9	M	H	L-M	16	48
140	S	31,32,58,59	49	M	M-H	L-M	68	45
142	S	58,59	76	M	H	L-M	4	58
144*	T	42,46	0	L-M	L-H	M-H	0	27
146*	T	42,46	0	L-M	L-H	M-H	2	3
148	T	58,59	15	M	H	L-M	0	24
150	T	31	7	M	M	L-M	6	60
152	T	58,59	34	M	H	L-M	19	39
154	T	31,42	6	M	M-H	L-M	0	43
158	T	58,59	43	M	H	L-M	0	8
160	S	58,59	60	M	H	L-M	0	12
164	T	58,59	31	M	H	L-M	0	4
168	T	42,32	22	M	H	M	0	6
170	S	31,32,33	45	M	M-H	L-H	0	10
172	T	31	1	M	M	L-M	0	18
174	T	31	0	M	M	L-M	0	2
178	T	31	1	M	M	L-M	1	29
180	T	31	3	M	M	L-M	8	76
182	T	31	2	M	M	L-M	64	50

* The map from the Soil Resource Inventory (SRI) indicates these stands may include juniper woodland soil types (34, 46) or non-forest soil types (35, 37, 47). The soils specialist believes these are errors in soil mapping, due to the scale that the SRI was mapped.

Expected Soil Conditions After Proposed Activities

These sub-units are the ones expected to have the most detrimental impacts after the proposed activities - they have the highest existing impacts and they have proposed tractor logging. Many of them also have proposed subsoiling of skidtrails.

			Expected Detrimental Impacts				
UNIT	Sub-Unit	ACRES	Alt. 1	Alt. 2	Alt. 3	Alt. 4	Alt. 5
			% of the sub-unit with detrimental impacts				
004	SILVIESNW03	7	8	15	16	10	15
004	COLD52	59	11	16	17	13	16
006	COLD54	11	12	13	13	14	13
006	H06B_UNK	8	10	17	17	12	17
012	COLD85	8	9	17	17	11	17
026	9610	20	9	16	16	11	16
028	9610	15	9	17	17	11	17
032	9614A	9	11	14	14	13	14
032	9612	29	8	16	16	10	16
034	9614A	91	11	13	13	13	13
056	VAT201B	15	12	13	14	14	13
056	9607S02C	51	10	17	12	12	17
057	9607S02A	15	8	15	15	10	15
058	9607S02A	29	8	16	8	10	15
059	9607S02C	5	10	12	12	12	12
062	VAT201A	8	8	15	16	10	15
063	9606A	8	8	16	16	10	16
067	29623	42	9	16	9	11	16
073	VAT295	15	10	17	12	12	17
074	VAT295	11	10	17	12	12	17
075	H75A_UNK	34	10	12	12	12	11
075	VAT347	13	12	14	14	14	13
077	29606	6	10	12	12	12	11
077	9602	17	9	17	17	11	16
078	29605	26	14	15	15	16	15
090	29602	22	8	16	16	10	16
090	9614D	54	10	12	12	12	12
090	H90_UNK	13	9	12	12	11	12
100	SNOW30	6	9	17	17	11	17
116	SNOW32A	45	8	15	16	10	16
118	SNOW34	35	11	13	13	13	13
120	SNOW37*	23	16	18	18	18	18
120	SNOW33*	25	15	17	17	17	17
130	JACK08	35	9	17	17	11	17
150	JACK08	8	9	11	11	11	12
154	DIPPVAT02A	38	11	16	17	13	16

180	JACK01B	19	12	13	14	14	13
180	JACK01A	58	12	13	14	14	13
182	JACK01B	41	12	13	14	14	14

* The reason that the acres and detrimental impacts in this table do not match those in Table SO-I is that this table deals only with the parts of the old units that are within unit 120, whereas Table SO-I deals with the whole old unit.

Subsoiling Suitability

These are the units for which subsoiling or dry soil harvest is proposed. Descriptions are from field soil assessment inspections.

Unit	Sub-Unit	Description
4	COLD52	Ridge tops have too much gravel. Up to 50% slopes
6	COLD54	Parts too steep
34	9614A	West side stony. Some slopes too steep. East side rocky.
56	VAT201B	Main skidtrails from last entry - all subsoiled.
56 & 59	9607S02C	Previous main skidtrails ripped.
73 & 74	VAT295	Suitable
75	VAT347	Slopes < 10%. Shovel penetration 2-10 inches
75	H75A_UNK	Some slopes too steep. Shovel penetration 4-10 inches.
77	29606	Suitable
78	29605	Suitable
90	9614D	Some slopes to 40%.
90	H90_UNK	Some slopes to 43%. Not real stony. Shovel penetration 2-14".
118	SNOW34	Some slopes too steep. Rockier at ridge top. Some rock outcrop.
120	SNOW37	Suitable
120	SNOW33	Quite a bit of shallow soil. >50% suitable.
150	JACK08	90% suitable
154	DIPPINGVAT02A	20% suitable. Too steep or stony.
180	JACK01A	Some too steep. 6-10 inch shovel penetration.
180 & 182	JACK01B	Suitable. Some too steep. 4-14 inch shovel penetration.

DRAFT

Sediment Export From Logging Units During Summit Fire Salvage

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2-23-01

Introduction

In August and September 1996 the Summit wildfire burned on Malheur and Umatilla National Forests in the Blue Mountains of Eastern Oregon. The Supervisor of Malheur National Forest decided to log part of the area. During the planning for the timber sales, some people expressed a belief that ground based logging would cause sediment to enter streams. In response the Supervisor made certain decisions, including a decision to monitor sediment movement on uplands. The goal of this monitoring is to help determine if logging after wildfire is consistent with maintaining water quality. The objective is to roughly quantify the sediment that left some units.

Methods

Study Area & Treatments

In consultation with the Blue Mountains Natural Resource Institute, the Forest selected twelve units as "Monitoring Areas," to evaluate the long term impacts of salvage logging on such variables as down woody material, snags, plants, and soil disturbance. This sediment study was also done on these units. The units do not represent all the variation in the Summit timber sale area; the following factors were considered when the units were selected:

- Yarding was by skidding.
- Stands were intensively burned.
- Stands occupy warm-dry or hot-dry biophysical environments, with generally southern exposure (three blocks were dominated by ponderosa pine).
- Soils were mostly mapped as mapping unit 181. These are usually stony, clay loam to clay

Table 1.

Unit	Block	Harvest	Harvest Dates Sep '98-Aug '99
323	1	Full	Feb-Apr, Aug
324	1	None	-
327	1	Partial	Feb-June
418	3	Partial	Oct-Nov
419	3	Full	Oct-Nov, Feb
420	3	None	-
421	2	Full	Dec-Feb
422	2	None	-
424	2	Partial	Dec-Jan
052	4	Full	Sep, Feb
520	4	None	-
522	4	Partial	Sep

soils with moderate to high surface erosion hazard, moderate to high compaction hazard, and low displacement hazard; derived from Clarno breccia geology. But soils in units 323, 324, 418, 419, 421, 422, and 424 have substantial amounts of ash, at least along their lower boundaries.

These factors indicate there is a higher risk of sediment production from these units than most units in the Summit fire area.

The study has three treatments (full harvest, partial harvest, and no harvest) replicated on four blocks. The blocking factor is geographic proximity; maximum distance from one end to the other in a block is about 0.8 miles. Blocks were about 0.8 miles apart. Within a block, the three treatments were randomly assigned. Total acreage of the eight harvest units is 230 acres.

Harvest started in block 4 and progressed to block 1. Commercial removal from the full harvest units was less than expected. In order to meet other objectives of the study, the full harvest units were re-logged in February (units 419 and 052) or August (unit 323). Logs from the re-log were decked on the landings and left.

Sediment Fences

Sediment was measured using sediment fences installed after logging. In blocks 3 and 4 installation was in fall 1998; in blocks 1 and 2 installation was in summer 1999. At least 3 sediment fences were installed along the lower boundary of each harvest unit. (For unit 327, skidders crossed the lower boundary and decked logs on a road below part of the unit. The road was considered the lower boundary below the landing, not the actual boundary.) One fence was installed in each of the four no-harvest units. The lower boundary of the eight harvest units were examined, and each part of the boundary classified into one of three classes of expected sediment export: high, medium, or low. In blocks 3 & 4, while assigning a particular part of the boundary to a particular expected sediment export class, the following factors were subjectively considered:

- Is there a bare area that can contribute sediment? How large is it? How steep is it?
- Is there a water bar, rutting or other micro-topographic feature to concentrate water?
- If there is an undisturbed area between the bare area and the boundary: How wide is it? How much ground cover does it have? How steep is it?

Inspection of the lower boundaries in spring 1999 indicated that an additional factor is probably more important:

- Is overland flow crossing the boundary, exiting the unit?

For blocks 1 and 2, this additional factor was considered. The intent was to place one fence at the most likely position for sediment export from the unit (highest high risk), a second fence at the highest medium risk, and a third fence at a typical low risk position. Some units had no high risk positions, so fences were placed at the two highest medium risk positions. In units 323, 327, and 419 an additional high risk fence was installed.

Sediment fences were installed according to a method of Bob Brown of the Rocky Mountain Research Station, Moscow, Idaho. Briefly, sediment fences are installed as follows:

1. Layout is along 35 foot-long arc, with either end of the arc more-or-less on the contour, and the middle of the arc about 4 horizontal feet below the contour.

2. A 7" deep, 4" wide trench is dug along the arc.
3. Erosion control fabric is laid along the bottom of the trench, and on the uphill side.
4. Trench is refilled and soil compacted into the trench, securing fabric in place.
5. Stakes are driven into the ground about 7" down slope from where the fabric emerges from the soil, about 2-3 feet apart along the trench. The stakes should be deep enough that the stakes are firm and can hold the expected weight of snow, water, and sediment. If this cannot be done, rocks are piled around the stakes to provide additional support
6. Fabric is folded back on top of the filled trenches to the stakes, and stapled to stakes, with strips of tarpaper.

The collected sediment was dried (100 ^oC) and weighed. Weights were converted to volumes with a conversion factor of 0.9 g/cm^3 (56 lb/ft^3).

Results

Visual Inspection

There was an unusually heavy snowpack during the winter of 1998-9, providing ample opportunity for spring runoff. The lower boundary of the harvest units were inspected for signs of overland runoff exiting the units following snowmelt. Indicators of overland runoff are rearrangement or scour of litter or soil. Table 2 shows the results. The indicators are not always clear; on questionable areas, I made the best judgment I could. Also, during different conditions, such as more rapid snowmelt or an intense summer thunderstorm, overland runoff may have occurred at more points.

Table 2. Number of points where overland runoff exits the unit.

Unit	Dates inspected	Points without roads	Points influenced by roads
		----------- count	------------
323*	5-12-99	3	3
327	5-12-99	1	1
418*	5-12-99	1	0
419	6-10-99	0	14
421*	5-5-99	0	5
424	5-5-99	1	0
052*	5-24-99	4	2
522	5-24-99	1	3
	total	11	28

* See Appendix for remaining inspection work

There were two types of area that produced overland flow without roads. Seven of the 11 points without roads are ephemeral water courses that don't have enough scour to qualify as Pacfish Category 4 streams. These ephemeral "streams" are usually in draws, and/or are located at the head of Category 4 "streams". Six of the 11 points are below areas where very shallow, rocky soil produces surface runoff. (Three of the six are also ephemeral "streams".) To minimize sediment export, these two types of area should receive as little disturbance as possible during logging.

Units 323 and 052 have more points where overland flow exits because there is less ash soil, and more relatively shallow, rocky, clayey soil, than most units. Because of this soil, there is less infiltration and more overland runoff. These facts illustrate that this type of soil has higher risk of sediment export than other types. The low amount of infiltration below culverts in units 522 and 052 also support this conclusion (see below). This type of soil is probably not common Forest-wide.

In no case did runoff originating on skidtrails reach the boundary of a unit, except where skidtrails lead down to a road. Skidtrails did produce runoff and erode, but the water infiltrated before it reaches the unit boundary, except where the skidtrail connected to a road. The waterbar placement guideline was "Where skidtrails are liable to channel water, waterbars are placed at 10 to 20 feet vertical spacing." This spacing was sufficiently close to prevent highly concentrated runoff.

Where skid trails captured concentrated runoff from culverts or draws, often there was noticeable rilling. (See Sediment Fence section below.) Of the 11 points where overland runoff exited units without roads, six probably were affected by skidding, and the other five may have been. The small size of rills, and the amount of undisturbed ground that filters sediment, indicated that probably only a little sediment exited units, except for roads.

Roads are a larger source of sediment than upland logging, because of their bare, compacted surfaces (including running surfaces and cutslopes), concentration of runoff, and entry into Riparian Habitat Conservation Areas. This study only looked at sediment from roads in so far as roads affect sediment export from the units. Sediment export from the units from roads occurs at three types of places:

- where a road leaves a unit, and the ditch and running surface carry water off;
- where a road forms part of the lower boundary, and water runs off the side;
- and where culverts above the units concentrate surface runoff that does not infiltrate before it leaves the unit.

There were 28 points where overland runoff exited units on roads

Four of the 28 points are where culverts above the units concentrate surface runoff that does not infiltrate before it leaves the unit. (One of the four is in an ephemeral draw.) Three of these four are in units 052 and 522, which had shallow, rocky, clayey soil, and a road above the units to concentrate runoff from the relatively large area of shallow, rocky soil above the road. In May 1999 overland runoff from the three culverts could be traced for more than 1000 feet down hill. Again, this type of soil has higher risk of sediment export than other types, as mentioned above.

Thirteen of the 28 points were on an 1100 foot road segment that formed part of the lower boundary of unit 419. The road has shallow ruts, but is outsloped, so water ran off the road at frequent intervals. This road segment receives surface runoff from upslope because of the shallow, rocky soil which the road traverses. But because of the close spacing of the drains, the road concentrates runoff only a little.

Other places that water from roads exited the units include 5 points where a road exits the unit, 3 culverts, and 3 drain dips. A few observations confirm that roads probably produce more sediment than skidding. For instance, possibly the largest sediment source in the twelve units is a point where a road fords a category 4 "stream" that traverses unit 419. (The RHCA was excluded from the unit, so this ford is not actually in the unit.) As another instance, rills have formed below two of the three culverts, and one of these rill reaches a category 4 stream.

Sediment does not do any damage until it reaches streams. Probably most sediment that exited units did not reach streams; there was at least 100 feet between the unit boundary and the stream. Runoff at six of the 11 points without roads appeared to reach streams. Runoff from seven of the 28 points influenced by roads appears to reach streams. Roads are often further from streams than unit boundaries, and runoff from roads is not as often in ephemeral "streams" as it is from units. So a lower percentage of the runoff and sediment from roads enters streams than from units.

In summary, visual inspections indicate there probably is very limited sediment export from logging units, because water flows across the boundary at only a few points, and because little to no sediment transport is visible at these points, and because most sediment is deposited before it reaches a fish bearing stream. The points most likely to produce sediment are roads and ephemeral water courses.

Sediment Fences

There are several serious problems with the quantitative sediment measurements.

- Blocks 1 and 2 were logged in the winter, and the fences were not installed until the next summer, so the first spring runoff was missed.
- I overestimated the number of places that might export sediment, and put 21 fences at places where overland runoff did not occur, and only 10 fences at points where overland runoff did occur. Of the 10 fences that were installed where runoff occurred, two collapsed due to ponding of water in them.
- Dirt from sources other than erosion collected on the fences.
- Two fences were placed so as to catch sediment from landings, but the decks of logs placed by the non-commercial harvest stopped most sediment export from these landings.

Despite these problems, some suggestive data emerged.

There was probably little or no runoff during either summer. Probably all sediment production occurred during spring runoff.

"Sediment" was collected from 13 of the 21 fences where it appeared there was no overland runoff. This "sediment" was due to dirt placed on fences by tree planters, burrowing animals, and dry ravel of the side of the trench. During sediment collection, all material that could be clearly identified as being from these sources was discarded, but there was often a residual that could not be clearly identified. The maximum "sediment" collected from fences that lacked overland runoff was 0.009 cubic feet and the average (including zero collections) was 0.001 cubic feet. The 0.001 cubic feet figure can be used as a zero.

In addition to the sediment fences located on unit boundaries, there was one located on a skidtrail in unit 522, about 300 feet below a culvert. That fence caught 0.256 cubic feet of sediment the first year and 0.037 cubic feet the second year.

Although inconclusive because of the problems, these data suggest that appearances are qualitatively correct – that little sediment is being exported from units, and that roads are a larger sediment source than skidding. The largest amount of sediment, 0.691 cubic feet, was from a haul road that formed a small part of the lower boundary of unit 323 The second largest amount of sediment was 0.100 cubic feet captured in a draw in unit 424. It is unknown where this sediment came from; it could have come from skidding, or from other sources such as burrowing animals or the fire. The third largest amount of sediment was 0.098 cubic feet, in unit 327. At this location, the sediment probably came from a skidtrail in the bottom of a steep draw (25% slope) that captured an ephemeral stream for about 100 feet. The lower end of the skidtrail was about 100 feet above the sediment fence. Sediment exported from the other seven measured point was negligible, though in some cases the measurement may be misleading, due to such factors as sediment fence collapse.

	Table 3. Sediment collected in fences where there was overland runoff.			
Unit	Location	Sediment collected first year	Sediment collected 2nd year	comments
		ft^3	ft^3	
		Without roads		
327	Draw at head of category 4 stream	0.098		
418	Draw at head of category 4 stream	0.000	0.002	
424*	In draw bottom	0.100		
052	In draw bottom below landing	trace	trace	
		Influenced by roads		
323*	Below drain dip	0.691		
323*	Below drain dip, below landing	0.005		Sediment collected is less than if the logs had not been decked on the landing during the "re-log".
327*	Below drain dip, below landing	0.008		Part of sediment fence collapsed first winter, probably losing most sediment
421*	Below culvert	0.011		
421*	Road ditch	0.003		
522	700 feet below a culvert	0.009	unknown	Part of sediment fence collapsed, some sediment may have been lost. Overland runoff diverted away from this fence before second winter

* These sediment fences were installed in the summer, after winter logging. The main flush of sediment was not captured.

Quantitatively, appearances can be misleading. I was surprised at how much sediment was exported in the three largest cases, and how little was exported from the draw below the landing in unit 052, and down the ditch of the 045 road in unit 321.

Based on the visual observations and the sediment fence measurements, I made a "guesstimate" of the amount of sediment exported from each of the 39 points where overland runoff exited the harvest units. The sum of the "guesstimates" totaled of 4.6 cubic feet (Table 4). For the 13 points that appeared to be connected to streams, I assumed that all the sediment possibly reached a stream. With this assumption, 2.3 cubic feet, one half of the exported sediment, possibly reached streams These sums depend more on the "guesstimates" than on the measurements, and it could be wrong by a factor of 10, perhaps more. But, although the evidence is inconclusive, the "weight of the evidence" indicates only a small amount of sediment was exported from the harvest units.

Table 4. "Guesstimate" of sediment exported from units.			
	Without roads	Influenced by roads	total
		Exported from units	
Exported from units	11 points	28 points	39 points
Exported from units	0.6 ft^3	4.0 ft^3	4.6 ft^3
		Possibly introduced into streams	
	6 points	7 points	13 points
Introduced into streams	0.3 ft^3	2.0 ft^3	2.3 ft^3

Effects of a Feller-Buncher Operation on Soil Bulk Density

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Summary

A feller-buncher tracked 11% of a logging unit while removing 61 trees per acre (5.4 mmbf/ac). Of the 11% tracked, 15% was compacted by the feller-buncher, for a total increase in compaction due to the feller-buncher of less than 2% of the unit. The site was a ponderosa pine forest with loamy soils and was harvested when dry or only slightly moist. Compaction due to the feller-buncher is in addition to 4% of the area compacted due to skidding on skidtrails spaced 120 feet apart. It is also in addition to 11.5% compacted from previous entries and 7.5% compacted by natural processes.

Introduction

For a few years, loggers on Malheur National Forest have been using feller-bunchers to cut logs and transport them to skidtrails. Soils specialists and others have been concerned that feller-bunchers will increase violations of soil compaction standards, because feller-bunchers are not restricted to skid trails. For instance, skidders and feller-bunchers impacted 54% of the land on an operation on the Wallowa-Whitman National Forest (Zaborski 1989). In this paper, I report effects of a feller-buncher operation on soil density. Miscellaneous observations are reported in the Appendix.

Methods

Site

The study site is on Malheur N.F., Burns R.D., Calamity Timber Sale, unit 3, in T19S, R32E, sec. 14. Two blocks were selected for sampling. Blocks were rectangles fitted within the unit so they would have fairly uniform soil, vegetation, and topography. Locations of the blocks were randomly selected. The north block is 20 acres and the south block is 10 acres. Blocks are similar to each other, though the north block had more Idaho fescue than the south block.

Vegetation is Ponderosa pine/elk sedge (Johnson & Clausnitzer 1992). Soil parent material is derived from andesite and basalt. Texture of the top 6+ inches is loam. In the 4 to 6 inch depth, gravel was 10% by volume. Coarse fragments increased with depth. Slopes face west, at 15 to 35 %. Elevation is 5600 feet. Average annual precipitation is about 18 inches (Carlson 1974). Snow normally blankets the ground all winter, so freeze-thaw loosening of compaction is probably minor.

Past logging

Age of stumps and increases in tree growth indicate the sampled blocks were logged two or three times previously. Several trees were released about 1960-63 by the removal of large pine, perhaps in the Jackknife Salvage Sale. There are more stumps in the north block than in the south block from this logging. Common practice at that time was to machine pile and burn slash accumulations. In the north block, there may have been another release about 1969, although I have not found records of a timber sale at that time. The area was also logged under the Mountain Spring Sale, sold in 1985. During this sale, trees over 18 inches were removed from the north block, whereas the south block had a lighter individual tree mark. I found no increased growth after the Mountain Spring sale. Much of the slash from the Mountain Spring sale was not treated. These previous entries left about 19 stumps per acre.

Feller-buncher logging

The Calamity sale removed 61 trees per acre, containing 5.4 thousand board feet per acre, and left 32 trees per acre.

The feller-buncher moved within 0 to 10 feet of each tree to be cut, cut the tree, carried it back to the skid trail, laid it in a bunch in the skid trail, and moved to the next tree. The feller-buncher was a Timbco T435 HydroBuncher. It weighed about 52000 pounds, with 7.9 pounds per square inch average ground pressure when unloaded, static, and level. Grousers covered about 10% of the track and they were 3 inches long. The feller-buncher had a 40 foot arm, and the cab and arm could rotate as far as desired. The cab was self-leveling, and the feller-buncher had no troble handling the 15-35% slopes in this unit. Skidding was done by a rubber-tired skidder on most of the north block, and by a tracked skidder on the south block. Skid-trails were about 120 feet apart. Skid-trail locations were selected by the feller-buncher operator. Trees were de-limbed at the landing.

Logging occurred beween late October and mid December 1992. When the feller-buncher logged the north block, the ground was powder dry within 1/4 inch of the surface; by the time the south block was logged a week later, rains had moistened the soil to about 3 inches. Most of the north block was skidded under these dry to somewhat moist conditions. The south block was skidded several weeks later when more than 8 inches of snow was on the ground, and the ground was moist to 9 inches deep.

Soil sampling

The 'before' bulk density and disturbance classes were estimated according to Region 6 guidelines (Hazard & Geist 1984). The south block was sampled in July 1990 and the north block was sampled in June 1991. Bulk density was determined by the core method, using cores 1.0 inch long and 1.9 inches in diameter. Samples were taken from the 4 to 6 inch depth. 31 transects with 10 samples per transects were used in both blocks. Additional samples were taken to estimate bulk density of soil that was apparently undisturbed, giving a total of 80 undisturbed samples. Because it was difficult to see where previous compaction had taken place, most 'undisturbed' samples were taken between two trees that were too close to permit tractor passage. This procedure may bias the estimate of undisturbed soil density, because soil between two trees may not have the same density as other soil.

The 'after' sampling was done differently, in order to reduce cost. The 'after' disturbance classes were estimated on the same transects as the 'before' sampling. Disturbance classes were 'non-tracked', 'feller-buncher', 'edge of skid trail', and 'skid trails'. The 'non-tracked' class included the area between the two tracks of the feller-buncher. Disturbance classes were observed in early May, 1993. Grouser marks made the feller-buncher tracks clear at that time; on only one part of one transect was it difficult to determine if and where the feller-buncher had tracked the ground. 'Edge of skid trail' denotes the disturbed areas on both sides of skid-trails that had not been clearly tracked. Most disturbance in the 'edge of skidtrail' area was due to brushing of tree tops along the ground, rather than to traffic.

Bulk density sampling was done using paired samples to compare 'non-tracked' with 'feller-buncher'. 'Feller-buncher' samples were taken as near as possible to the start of a transect, and the paired 'non-tracked' sample was taken as near as possible to its paired 'feller-buncher'sample, considering that it had to be on the transect and 12 to 18 inches from a track. (Flock (1988) found that samples taken 2 feet outside tracks had the same bulk density as samples taken further away.) 'Edge of skid-trail' samples were taken the same way. Fourty-four 'feller-buncher' pairs were taken and 18 'edge of skid trail' pairs were taken, each pair on a different transect. Sampling was done in May and July, 1993.

Statistics

The effect of the feller-buncher on soil density can be described by the equation

$$f = n + e + ef$$

where f is the measured bulk density of the 'feller-buncher' samples.
n is the measured bulk density of the paired 'non-tracked' samples.
e is a random variable that accounts for differces in the original bulk densities of the f & n samples and for the effect of measurement error.
e has a mean of 0 and a variance, var(e), to be estimated
ef is the effect of the feller-buncher on bulk density. ef is a random variable with a mean [mean(ef)] and a variance [var(ef)], both of which are to be estimated. I assume mean(ef) is independendent of n and e. (That is, I assume higher bulk density soil is compacted as easily as lower bulk density soil.)

Mean(ef) is estimated by: mean(ef) = mean(f - n)

I estimated var(e) by: var(e) = 0.7 * var(a-b) where a and b are paired 'before' samples located 10 feet apart. The '0.7' coefficient reflects my guess about the effect of the n and f samples being closer together than 10 feet.

I estimated var(ef) by: var(ef) = var(f-n) - var(e).

I assumed the ground the feller-buncher tracked had the same statistical distribution of bulk densities as found in the 'before' sampling. I assumed the effects of the feller-buncher were in a normal statistical distribution with mean(ef) and var(ef). I then estimated the statistical distribution (histogram) of bulk densities for the area tracked by the feller-buncher. In order to do this, I generated values by taking each 'before' bulk density value (308 values for each block) and adding a random value, drawn from a normal distribution with mean(ef) and var(ef). I did this addition using 20 different random values, for each 'before' value, to generate a total of 6160 values for each block. This statistical distribution indicated percent of soil compacted, for the area tracked by the feller-buncher. (This estimate was checked against the percentage of the 44 tracked samples that were compacted, and the two estimates agree very well.) I then subtracted the percent of soil compacted 'before' feller-buncher logging to find the increase in percent of soil compacted by the feller-buncher.

A similar procedure was used for the 'edge of skid trail' samples.

Results & Discussion

The results presented in the the text below is an average of the north and south blocks. Some of the results presented in tables and figures are for the individual blocks. When comparing numbers in the text with numbers in tables, this difference should be kept in mind to avoid confusion.

Undisturbed bulk density & Forest Plan standards

Eighty samples from areas that appeared to be undisturbed had an average bulk density of 0.881 Mg/m^3 and a standard deviation of 0.097 Mg/m^3 (Fig. 1). There was no difference between the north and south blocks. By FSM definition, non-ash soil is compacted if it has a bulk density 15% greater than the mean undisturbed soil. So the threshold for recognizing compacted soil is 1.013 Mg/m^3. Six of the 80 undisturbed samples had a bulk density higher than 1.013 Mg/m^3, so 7.5% of the soil was 'compacted' before disturbance. This apparent 'compaction' is due to natural variation in bulk density. The 7.5% value is higher than the 1% found by Sullivan (1989) on soil developed in volcanic ash. However, Geist and coworkers (1989) found standard deviations up to 10% of the mean on volcanic ash soils. In a soil where the standard deviation is 10% of the mean, 7% of the soil would be compacted by natural processes, assuming statistically normal distribution. Ash soil is derived from relatively uniform parent material, so other soils may be more variable.

The Forest Plan states as a standard "The total acreage of all detrimental soil conditions shall not exceed 20% of the total acreage within any activity area, including landings and system roads." Because

3.5% of the unit was in roads and landings, the standard was violated if 16.5% of the sampled area was compacted.

Impact of previous logging

On the two blocks, an average of 19% was compacted before this logging operation, with an increase in average bulk density of 0.034 Mg/m^3 (Table 1).

Table 1. Bulk densities before feller-buncher logging

Block	Mean Bulk Density	Area Compacted
	Mg/m^3	%
South	0.903	14.0
North	0.926	24.3

It is not intuitively clear how a small increase in bulk density (4%) can cause a large increase in the percent of an area compacted (11.5% = 19% - 7.5%). Geist and coworkers (1989) found similar results. They attributed this result to loosening effects, like displacement, partially counterbalancing compaction.

```
Relative Abundance,
line count
    |                                    NNNN
    |                                    XXXX
    | UUUU = 'undisturbed' only          XXXX
    | NNNN = North block only    UUUU    XXXX
    | XXXX = both 'undisturbed'  UUUU    XXXX
    |       and North block      UUUUUUUUXXXX
    |                            UUUUUUUUXXXX
    |                            UUUUUUUUXXXX
  30|                            UUUUUUUUXXXX
    |                            UUUUUUUUXXXX
    |                            UUUUUUUUXXXX     c  Compacted
    |                            UUUUXXXXXXXX     c
    |                            UUUUXXXXXXXXNNNN c
    |                            UUUUXXXXXXXXNNNN c
    |                            UUUUXXXXXXXXNNNNNcNN
    |                            UUUUXXXXXXXXXXXXXcXX
    |                            XXXXXXXXXXXXXXXXXcXX
    |                            XXXXXXXXXXXXXXXXXcXX
  20|                            XXXXXXXXXXXXXXXXXcXX
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
    |                        UUUUXXXXXXXXXXXXXXXXXcXXNNNN
  10|                        XXXXXXXXXXXXXXXXXXXXXcXXNNNN
    |                    UUUUXXXXXXXXXXXXXXXXXXXXXcXXNNNN
    |                    UUUUXXXXXXXXXXXXXXXXXXXXXcXXNNNNNNNN
    |                    XXXXXXXXXXXXXXXXXXXXXXXXXcXXNNNNNNNN
    |                    XXXXXXXXXXXXXXXXXXXXXXXXXcXXNNNNNNNN
    |                    XXXXXXXXXXXXXXXXXXXXXXXXXcXXXXXXNNNN
    |                    XXXXXXXXXXXXXXXXXXXXXXXXXcXXXXXXNNNN
    |                    XXXXXXXXXXXXXXXXXXXXXXXXXcXXXXXXNNNN
    |                    XXXXXXXXXXXXXXXXXXXXXXXXXcXXXXXXXXXX

|____________NNNNNNNNXXXXXXXXXXXXXXXXXXXXXXXXXcXXXXXXXXXXNNNNNNNNNNNNNNN
N___
    |              |              |              |              |
|
   0.4            0.6            0.8            1.0            1.2
1.6
                                  Bulk Density, Mg/m3
```

Fig. 1 Overlayed histograms for 'Undisturbed' samples and for samples from the North block. Histograms are scaled so that both include about the same area. Each 'UUUU' and 'XXXX' stands for approximately 0.43 'Undisturbed' samples (n=80). Each 'NNNN' and 'XXXX' stands for approximately 1.66 North block samples (n=309). Observations to the right of the vertical lines of 'c's are compacted; observations to the left are not compacted.

There are two additional considerations that can help account for the large increase in the percent of the area compacted, despite the small increase in bulk density: (1) A small increase over a unit is probably due to a large increase on a small part of the unit. For instance, if 1/3 of the unit had been tracked, the increase on this 1/3 was 0.102 Mg/m^3 (three times 0.034). (2) As Figure 1 shows, there is much undisturbed soil that is not far below the 'compacted' density, and it takes only a small increase in bulk density (for instance, 0.102 Mg/m^3) to 'compact' this soil. Thus, most of the soil with bulk densities greater than 1.013 Mg/m^3 had not undergone a bulk density increase of 15%.

Impact of feller-buncher logging

The feller-buncher increased bulk density by 0.047 Mg/m^3 (Fig. 2, Table 2). This is a significant increase by Student's t-test. The increase is comparable to Zaborske's (1989) results of 0.056 Mg/m^3 and Floch's (1988) result of 0.046 Mg/m^3, and is less than McNeel & Ballard's (1992) result of 0.165 Mg/m^3. The feller-buncher compacted between 10 and 20 percent of the land it passed over (Fig. 2, Table 2). This is somewhat more than the area occupied by the grousers on the tracks. The edge of the skidtrail was compacted very little. The compaction that did occur on the edge of the skid trail was partially offset by deposition of low bulk density soil brushed from the skidtrail.

Table 2. Effect of feller-buncher track and "edge of skidtrail" surface conditions on soil bulk density.

Surface Condition	Increase in bulk density		Standard Deviation of	Increase in percent of area compacted[c]		
	mean	se[a]	Increase[b]	mean-se[d]	mean	mean+se[d]
	-------	Mg/m^3	-------	---------	%	---------
Feller-buncher	0.047	0.019	0.065	10	15	20
Edge of skidtrail	0.002	0.031	0.081	-2	5	12

a. Standard error of the estimate of the mean.
b. Standard deviation is the square root of the variance, var(ef), which was estimated as described in the Statistics section.
c. Total compaction is percent in this column plus the 'before' percents from Table 1.
d. Increases in percents calculated using the mean increase (column 1, this table) +/- the standard error of the increase (column 2, this Table).

The feller-buncher tracked 11% of the unit, in addition to the 18% disturbed by skidtrails and edge of skidtrails (Table 3). This contrasts with Zaborske's (1989) results of 7% impacted by feller-buncher alone and 47% impacted by skidders. Comparison of Table 1 with Table 3 indicates that this operation compacted about 6% of the unit, of which more than 4% is attributable to skidtrails and less than 2% is attributable to the feller-buncher. However Floch (1988) found that the area between tracks was somewhat compacted. So compaction due to the feller-buncher may be slightly greater than I estimated.

```
Relative Abundance,
line count
    |                              NNN
    |                              NNN          NNN = non-tracked North
Block
    |                              NNN          FFF = Feller-buncher
tracked
    |                              NNN          XXX = Both NNN and FFF
histogram
    |                              NNN
    |                           NNNNNN
    |                           NNNNNN   c
    |                           NNNNNN   c      Compacted
  30|                           NNNXXX   c
    |                           NNNXXX   c
    |                        NNNNNNXXXFFFc
    |                        NNNNNNXXXFFFc
    |                        NNNNNNXXXXXXc
    |                        NNNXXXXXXXXXc
    |                        NNNXXXXXXXXXcFF
    |                        NNNXXXXXXXXXcFF
    |                        NNNXXXXXXXXXcFF
    |                        NNNXXXXXXXXXcFF
  20|                        NNNXXXXXXXXXcXXNNN
    |                        NNNXXXXXXXXXcXXXXX
    |                        NNNXXXXXXXXXcXXXXX
    |                        XXXXXXXXXXXXcXXXXX
    |                        XXXXXXXXXXXXcXXXXX
    |                        XXXXXXXXXXXXcXXXXX
    |                        XXXXXXXXXXXXcXXXXXFFF
    |                     XXXXXXXXXXXXXXXcXXXXXFFF
    |                     XXXXXXXXXXXXXXXcXXXXXFFF
    |                     XXXXXXXXXXXXXXXcXXXXXFFF
  10|                     XXXXXXXXXXXXXXXcXXXXXFFF
    |                  FFFXXXXXXXXXXXXXXXcXXXXXFFF
    |                  XXXXXXXXXXXXXXXXXXcXXXXXFFFFFF
    |                  XXXXXXXXXXXXXXXXXXcXXXXXFFFFFF
    |               NNNXXXXXXXXXXXXXXXXXXcXXXXXFFFFFF
    |               NNNXXXXXXXXXXXXXXXXXXcXXXXXXXXFFF
    |               XXXXXXXXXXXXXXXXXXXXXcXXXXXXXXFFFFFF
    |               XXXXXXXXXXXXXXXXXXXXXcXXXXXXXXFFFFFF
    |            FFFXXXXXXXXXXXXXXXXXXXXXcXXXXXXXXFFFFFFFFF

|_________XXXXXXXXXXXXXXXXXXXXXXXXXXXcXXXXXXXXXXXXXXXXXFFFNNN___________
____
    |           |           |           |           |           |
|
   0.4         0.6         0.8         1.0         1.2         1.4
1.6
                                  Bulk Density, Mg/m3
```

Fig. 2 Overlayed histograms for samples from the North block and for the calculated bulk density of the 11% of the unit tracked by the feller-buncher. Histograms are scaled so that both include about the same area. Each 'NNN' and 'XXX' stands for approximately 1.53 samples (n=309). Samples to the right of the vertical line of 'c's are compacted; samples to the left are not compacted.

Table 3. Effects of logging on area compacted.

		North Block		South Block	
condition	% of block in this condition	% of land in this condition compacted	% of block compacted[a]	% of land in this condition compacted	% of block compacted[a]
non-tracked	71	24[b]	17	14[b]	10
tracked by feller-buncher	11	39[c]	4	29[c]	3
skidtrail	8	70[d]	6	70[d]	6
edge of skidtrail	10	29[e]	3	19[e]	2
total	100	-	30	-	21

a. Percents in this column are derived by multiplying (% of block in this condition) times (% of land in this condition compacted).
b. Percent of 308 samples taken before feller-buncher logging that were compacted, from Table 1
c. Percent of 'non-tracked' land compacted plus the 15% from Table 2.
d. Assumed value (5 of 8 samples taken from skidtrails were compacted.)
e. Percent of 'non-tracked' land compacted plus the 5% from Table 2.

The 6% increase pushed the unit from about 19% compacted to about 25% compacted. Impacts from the feller-buncher are in addition to impacts from prior logging and from skidding. If the feller buncher had not been used, about 23.4% of the unit would have been compacted. If it had been realized before hand that the unit was in violation of standards, subsoiling would have been prescribed to rehabilitate the compacted soil.

Extrapolation to other operations

Impacts from the feller-buncher in this operation were small. However, that will not be the case for all operations. Factors that may give different results on other operations include:

1. Pattern of felling and skidding. If skid trails are closer than 120 feet, more area will be compacted by skidding. This factor probably accounts for the difference in results between this study and Zaborski's (1989) study.
2. The 'compactability' of the soil. I believe moist soil is more compactable than dry soil, and I recommend that feller-bunchers not be used on moist soil. Abundant woody debris on the forest floor probably reduces the pressure applied to the mineral soil and resulting compaction. Soil type influences compactability.

3. Number of trees cut by the feller-buncher. The more trees, the more area that will be tracked by the feller-buncher. I hypothesize the relationship is proportional (i.e. twice as many trees cut cause twice as much traffic).
4. Machine factors, such as ground pressure, total weight, track design, and vibration affect compaction in tracked soil. Maneuverabilty and reach of the boom may affect the amount of land tracked.

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Appendix
Miscellaneous Observations

1. The 'non-tracked' samples taken after logging had an average bulk density higher than samples taken before logging. It is unlikely that the feller buncher compacted soil at the 4 to 6 inch depth, 1 to 1.5 feet outside the track. More likely, the apparent increase is due to the fact that samples taken by two people after logging have a higher bulk density than samples taken by other people who sampled after logging. I adjusted the bulk density values for samples taken by those two people by a factor of 0.93.

This problem raises a question about whether measurement of bulk density with such short cores is an objective measurement. During sampling, soil is picked off both ends of the soil core, until the soil is 'level' with the ends of the core. Different people may see sligtly different configurations as 'level'. These differences may be significant with short cores.

2. One mitigation that I recommend on tractor units is that new skidtrails be located on old skidtrails, where practical. If compacted soil is compacted more, the percent of a unit compacted does not increase. However, this mitigation rests on the assumption that areas off of visible old skidtrails are less likely to be previously compacted than areas on visible old skidtrails. Data from this study indicate the limitations of this assumption: off of old skidtrails, 18% of the samples were compacted, and on the old skidtrails, only 26% of the samples were compacted. If this is typical, staying on old skidtrails may not be a very effective mitigation.